THE ECONOMIC THEORY GUIDING FIRE-PROGRAM ANALYSIS SYSTEM

Response to Questions Submitted by Howard Roose

Prepared By

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PREFACE

This is a written response to the following request made by Howard Roose. Howard's original questions are reproduced in Appendix A.

> "Attached you will find a list of questions regarding the economic theory we are seeking your professional help with as we embark upon design and development of a new federal agencies wildland fire program analysis tool. The Federal Fire and Aviation Leadership Council Budget Team and the Fire Program Analysis System Core Team are asking those of you whom choose to participate with this effort and to attend a meeting in Boise, Idaho August 28 and 29, National Interagency Fire Center, Training Building, Salmon River Room, starting at 0800 on the 28th.   Could each of you please provide a written response to the questions, back to me by the close of business, August 8th, 2002. Should you have questions please feel free to call. Thank You(See attached file: Questions Relating to the Economic Theory Guiding FPA.doc)"
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INTRODUCTION

Our review of your set of questions revealed three central themes. These themes are central to developing a clear understanding of the cost effectiveness analysis (CEA) economic theory and related processes. These themes are:

- The micro-economic principles of CEA
- Measuring effectiveness, and
- Scalability

References to the questions are denoted in each section heading by “Q1” for question one, “Q2” for question two and so on.

Please recognize that there will be additional subjects that will need to be addressed as the development of the FPA progresses, but these three themes are central to the questions posed and critical to the successful eventual development of the FPA. Therefore, we will provide an explanation and development of each of these three themes before specifically addressing the provided questions. This will enable us to address the questions in a structured and informed context.

BACKGROUND ON CEA

While CEA was developed long ago, its modern development primarily stems from cost analysis of military expenditures during the cold war. Here the process was used by the President’s Council of Economics Advisors. Subsequent applications have focused on health care and public education. Currently, economists are applying CEA to the issues of homeland security. In each of these applications, public scrutiny over rising expenditures has been intense and measurement of the direct benefits is often regarded as impractical or even inappropriate.

To address issues of rising government expenditures, the first Bush administration began the process of would become the Government Performance and Results Act of 1993, also known as the “Results ACT”, or GPRA. The relevance of the act to CEA is that it seeks accountability in terms of establishing and reporting performance measures in the planning process. Meaningful performance measures are what economists had been referring to as effectiveness measures.

As issues of public accountability intensified, the economics textbooks on benefit cost analysis increased their coverage. For example, in the main-stream benefit cost text “*Cost-Benefit Analysis: concepts and practice*,” (1996) Boardman et al devote an entire chapter to CEA. In a leading forest economics text *Principles of Forest and Environmental Economics* (2001), Rideout and Hesseln provide the first development of CEA in a forestry and benefit cost context. This old field is rapidly expanding to address issues of public policy and accountability where benefits are too costly or impractical to measure. Entire text books have now been devoted to the topic such as "*Cost Effectiveness Analysis: Methods and Applications* (2nd ed.) by Levin and EcEwan, 2001 have been devoted to CEA.

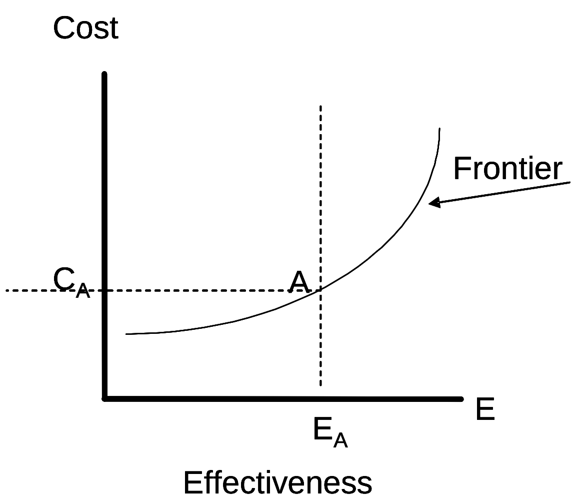
MICROECONOMICS OF CEA

The microeconomics of CEA are developed below using a single measure of effectiveness to illustrate the basic concept and then using two different measures in a way that applies to many of the questions asked by Howard Roose.

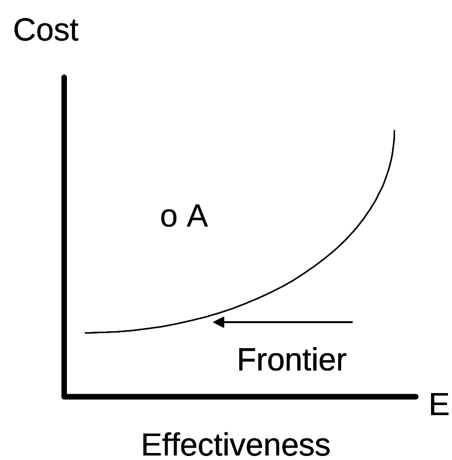
SINGLE MEASURE OF EFFECTIVENESS (Q3, Q5 AND Q7)

Before the field of CEA developed it was not unusual to encounter descriptions that defined cost effectiveness in terms of a fixed quantity of product to be produced at least cost. More recent developments often expand the analysis to address a scale of quantity produced with each quantity produced at least cost. Each of these descriptions are illustrated in the two CEA panels below:

Panel A: Fixed quantity



Panel B: Variable quantity.



In panel A, point A denotes the least cost method of achieving the fixed output or effectiveness level E_A. Panel A can also be used to show how a fixed budget set at C_A would correspond with effectiveness level E_A. This depiction of a fixed budget is particularly relevant because budgets are always limited. Given a budget set at C_A, the optimal level of effectiveness is given by E_A.

Panel B shows a range of effectiveness that can be produced with increasing effectiveness attained at increasing cost. The CEA frontier denotes the maximum attainable effectiveness for any particular cost level. Points on the interior of the frontier such as point A in panel B are also attainable, but more effectiveness can be attained for the same cost, so they are termed by economists at "technically and economically inefficient." The struggle in most public endeavors is attaining points on the frontier, as opposed to interior points like A and this should not be understated.

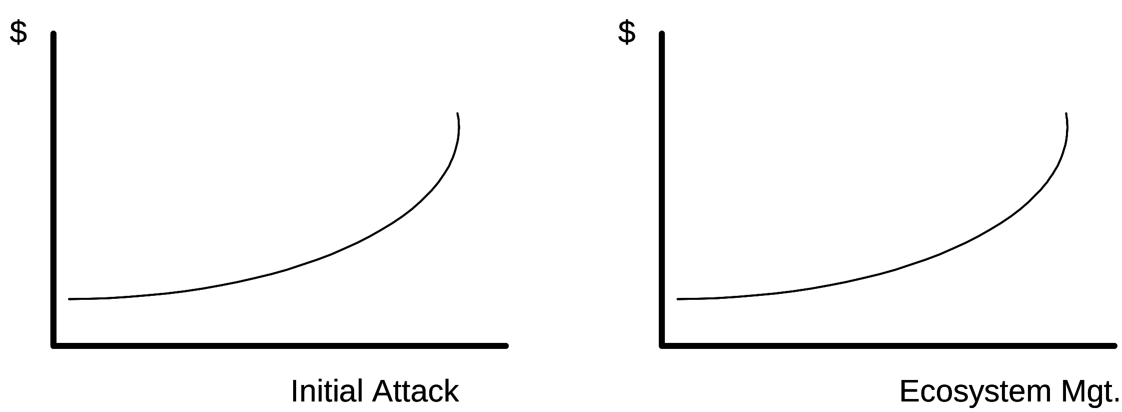
The principle of diminishing returns requires that the slope of the frontier eventually increases at an increasing rate. This principle applies wherever the slope is increasing. It could apply to the entire frontier or part of it. The upward sloping frontier looks like a supply curve from basic economics, and it is. Therefore, we can appropriately think of Panel B as showing a supply curve for producing some output like initial attack success. As with typical supply functions, an improvement in technology or an increase input costs will act to shift the supply curve out to the right. Under these conditions, more effectiveness can be produced for a given cost.

Panels A and B depict a smooth upwardly increasing slope as a basic model for developing the understanding of CEA with a single measure of effectiveness. In practice, portions of the supply curve could be more linear, or even have discontinuities that would need to be addressed in the application stage.

The basic microeconomics of CEA with a single measure of effectiveness can be expanded to include results of two treatments with a budget constraint. This treatment is developed in Rideout and Hesseln, 2001 and provided in appendix B to this paper. It is not developed here because the questions provided by Howard Roose often focused on issues of multiple measures of effectiveness.

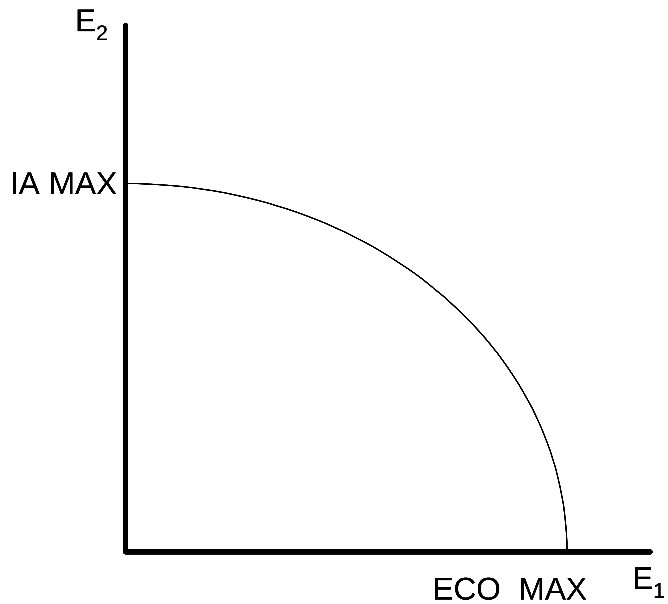
CEA WITH MULTIPLE MEASURES OF EFFECTIVENESS (Q1B, Q5, Q9A)

Adding a second measure of effectiveness relates to several of the questions raised by Mr. Roose and adds considerable complexity to the analysis. Continuing with the cost effectiveness frontier concept consider effectiveness of initial attack IA and effectiveness of ecosystem management ECO. The specific definitions of effectiveness are unimportant now, but will be addressed in the next section on "Measuring Effectiveness." A cost effectiveness frontier could be constructed for each as in the following two panels.



Now consider a fixed budget used to produce these two measures of effectiveness such as initial attack success E_1 and ecosystem management E_2. The basic framework is illustrated in the following figure that economists call the "Production

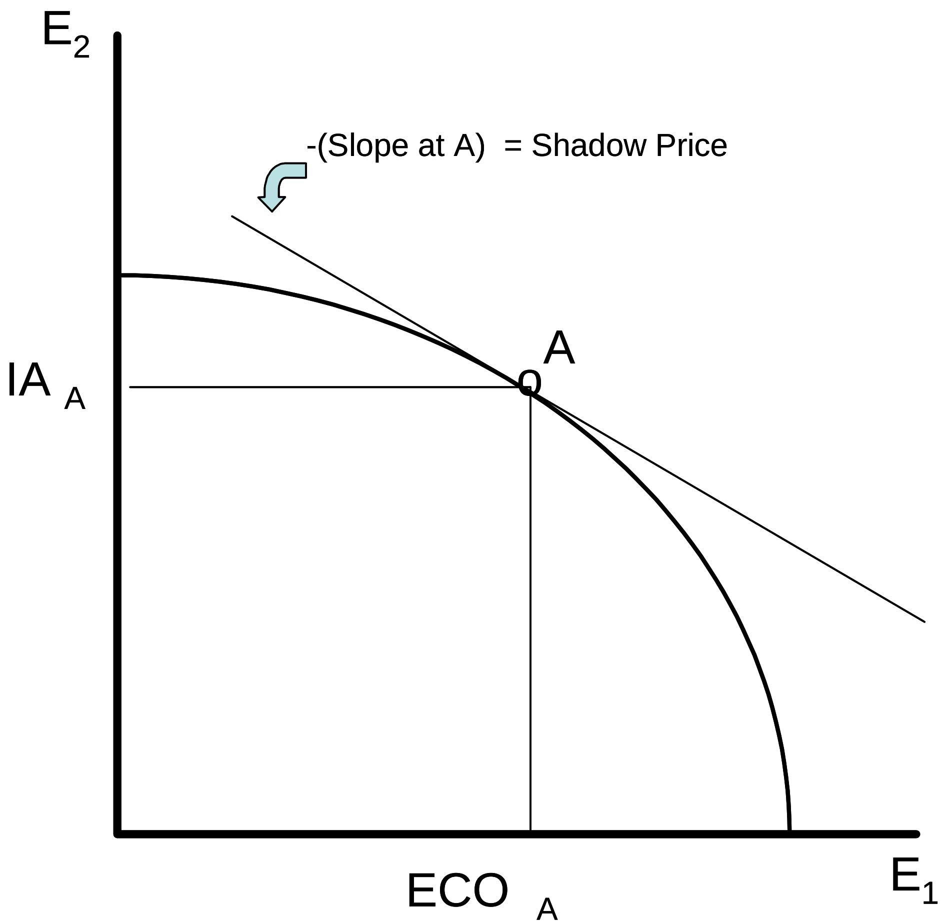
Possibility Frontier." If all of the budget were allocated to initial attack E_1, then the maximum effectiveness that could be attained for initial attack would be IA MAX and some incidental amount of ecosystem management, corresponding with the origin would also be produced. Similarly if the entire budget were allocated to ecosystem management, then the maximum effectiveness of ECO MAX would be produced and some incidental amount of initial attack would also be produced corresponding with the origin.



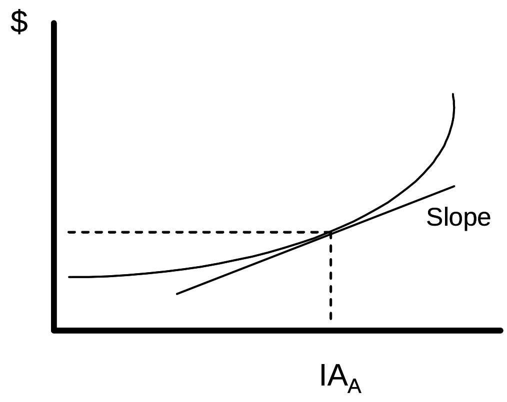
The curve connecting IA MAX with ECO MAX represents technically efficient combinations of the two measures of effectiveness that can be produced with a fixed budget. Points on the interior are inefficient as more of at least one measure can be produced at no additional cost. Points on the exterior are unattainable with current technology and input prices. The problem can be viewed as two CEA problems as shown in the two supply curves or in the context of the tradeoffs between the effectiveness measures shown in the production possibility frontier. Several of the questions posed by Mr. Roose relate to the relative values and management of the tradeoffs between measures of effectiveness. The slope of the production possibility frontier has particular meaning with regard to shadow prices.

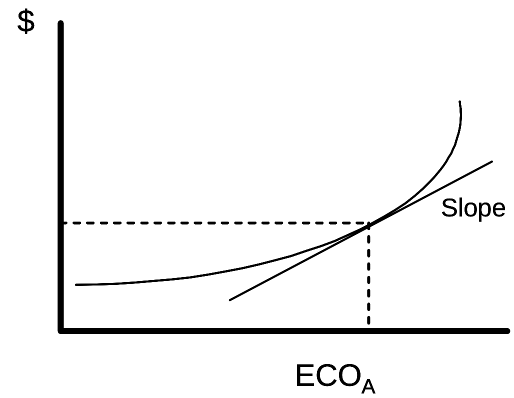
SHADOW PRICES (Q2B, Q9A)

Let's pick a particular point on the production possibility frontier such as point "A" in the figure below. Point A corresponds with initial attack effectiveness level IA_A and ecosystem management level of effectiveness ECO_A. The slope on the production possibility frontier at A defines the shadow price of the two effectiveness measures. In economics the negative of this slope is also known as the rate of product transformation, or the rate at which one measure can be sacrificed to obtain more of the other. In CEA, this slope or shadow price would be equivalent to the rate of effectiveness transformation or "REA." To the extent that the slope changes along the frontier, the shadow price would also change.



Mathematically we can show that this shadow price can also be obtained through the two supply curves. In the diagram below the supply panel for initial attack shows production of IA_A and the panel depicting the supply of ecosystem management effectiveness depicts supply level ECO_A. Each of these points corresponds with a slope along its supply curve. That is, at point IA_A a tangent line to the supply curve denotes the slope and the marginal cost of producing initial attack effectiveness. Likewise the slope of the ECO_A supply curve denotes the marginal cost of producing ecosystem management effectiveness. The ratio of these slopes or marginal costs MC_{IA}/MC_A is also the shadow price. The ratio of the supply curve slopes equals the rate of effectiveness transformation and defines the shadow price of the two effectiveness measures. It is now clear that there is an important relationship between the supply curves and the production possibility frontier. Mathematics, not shown here, can make this clear. The analysis can be extended beyond two measures of effectiveness, but the two dimensional graphs would not be useful.





There are a variety of techniques for revealing and checking the shadow prices. For example there are a variety of techniques that can be used Ex Ante including those described by Bell (1976) or methods that incorporate survey results or tests of reasonable ranges of values. Ex Post measures can also be used where the sensitivity analysis or programming techniques are used to reveal the slopes defined above. Ex Post and Ex Ante techniques can also be compared to provide checks on consistency.

CONSTRUCTING AN EFFECTIVENESS INDEX (Q1A, Q2A, Q2B)

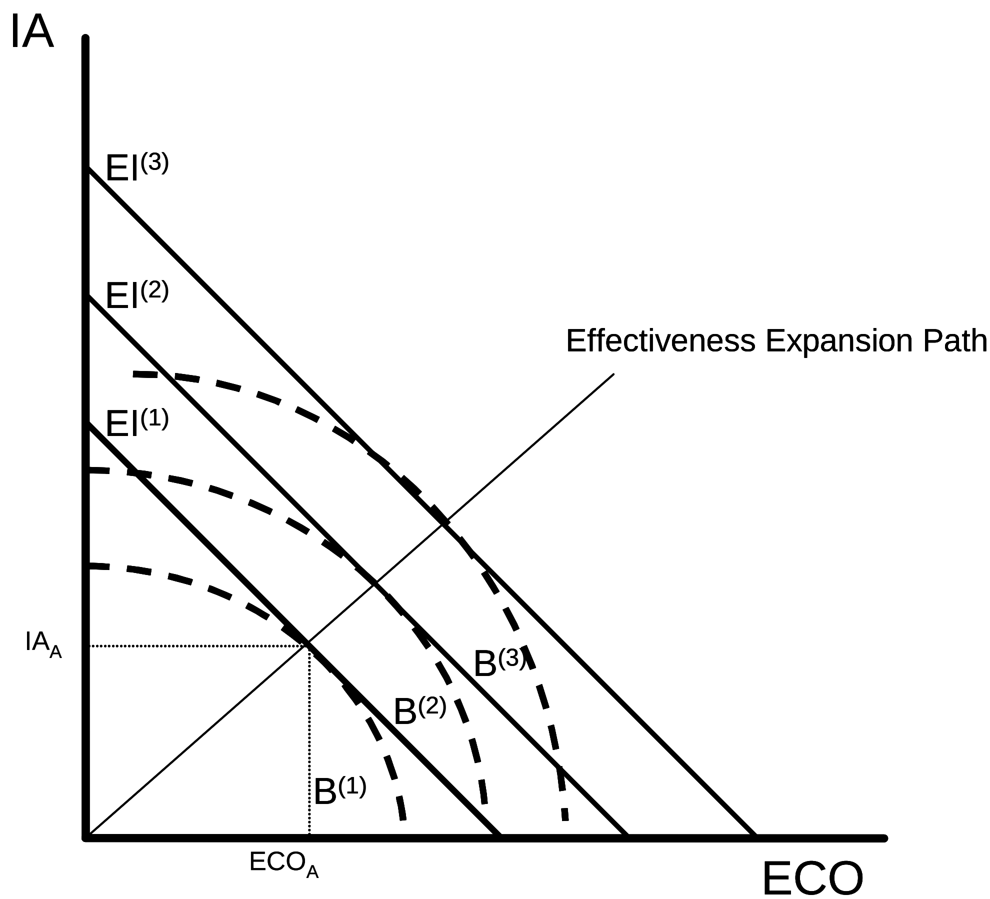
With defined levels of effectiveness such as IA_A and ECO_A shadow prices defined by the slopes explained below, constructing an effectiveness index is straightforward. For the shadow price of initial attack (SP_{IA}) and ecosystem management (SP_{ECO}) the effectiveness index value "EI" at point A is defined by:

$$EI_A = IA_A * SP_{IA} + ECO_A * SP_{ECO}.$$

The index value is calculated by multiplying the shadow prices by their amount of effectiveness. Assuming linearity in the parameters, higher index values are preferable to lower values.

CHANGING THE BUDGET LEVEL (Q6, Q9C)

Increasing the budget increases the amount of effectiveness that can be produced. The figure below shows the effectiveness production possibility frontier at three budget levels B^1, B^2, and B^3. Levels of effectiveness "A" are reproduced below for budget level B^1 . By expanding the budget, the frontier is moved outward. By keeping the initial shadow prices, the optimal levels of effectiveness are shown on each frontier by the effectiveness expansion path. If for example, B^3 was the initial budget request, but it were only 80 percent allocated (level B^2), then the allocation between initial attack and ecosystem management effectiveness would be given by the tangent point on B^2. This can easily be read at different budgets by moving along the expansion path.



MEASURING EFFECTIVENESS (Q1, Q2A, Q8D)

An effectiveness measure is a metric used to quantify the effectiveness of an action. They can be used at all levels of planning, from tactical to strategic. There are five main levels of planning that make up a suitable framework for the application of effectiveness measures. See the chart below.

Level (highest to lowest)	Purpose	Wildland Fire Example
Policy Outcomes	Indicate effectiveness of policies in achieving basic goals	Reduce the risk of wildland fires/Protection
Program Outcomes	Indicate effectiveness of programs ability to achieve outcomes	Reduce the amount of condition class III acres by 50% in 2003
Outputs/Indicators	Actual work products produced (quality, cost, quantity, etc...)	Number of effective acres treated
Process	Production methods (efficiency, quality, effectiveness, etc...)	Prescribed Fire, mechanical treatments, etc...
Inputs	Resources required	Hand crews, engines, etc...

Figure 1 (adapted from Osborne 2000)

Ideally, decision makers will start from the top level of planning and work their way down the list, creating objectives which the agency will strive to accomplish. Then, effectiveness measures should be chosen so that they serve as a sufficient input to the next level of decision. Looking at the bottom of the chart for example, how well did the crews execute the prescribed burn and how well did the prescribed burn increase the number of effective acres treated and how well did increasing the effective acres treated reduce the condition class III acres and so on up the chart.

Creating effectiveness measures is a difficult process. Done poorly, the measures will not accurately depict the overall performance of the action. Conversely, if the measures are chosen wisely, agencies can begin to manage for performance and have a standard upon which to evaluate alternative solutions that meet the stated objective. There are two main features that an effectiveness measure must have. Effectiveness measures must be relevant and measurable. At first glance this seems intuitive, but it deserves another look. Often times, the most relevant measures are the most difficult to measure and the ones that are easy to measure are often not the most relevant. To illustrate this, let's take a closer look at examples of effectiveness measure that could be used to evaluate wildland fire performance.

Performance measures need to capture both quantity and quality of the action being performed. Others have reported the following five major attributes of performance measures:

Effectiveness: how successful inputs are at producing desired outputs.
Efficiency: cost per unit of process or output.
Quality: how well an activity is performed.
Cost-effectiveness: level of outcomes can be achieved for the cost.
Quantity: the amount of an output produced.

For example, assume that a possible policy outcome would be to reduce the fire's ability to inflict damage on our natural resources and communities. To determine how successful we are in achieving the desired result, performance measures can be applied.

For presuppression/prevention, a performance measure could be the percent of acres not in risk of a potential severe wildland fire. More specifically, a "quality acre" can be created that combines the number of acres, or acres burned, with the condition class rating. In fuels treatment for example, instead of measuring the raw number of acres treated, agencies could report the number of "quality acres" treated, where an acre of each condition class (I, II, III) is considered 0.5, 0.75 and 1 quality acre respectively. The effectiveness measure would be the percent of acres that are condition class I after a certain treatment and/or the amount of quality acres treated. This would provide managers with a much clearer picture as to what is being done to reduce the risk of wildland fire, and where their money is being spent.

Another effectiveness measure for presuppression could be how many targets (houses, acres, etc.) could a severe wildland fire destroy after a treatment was completed. Clearly, an effective treatment would significantly reduce the threat to such targets. Any number of treatments can adopt this measure of effectiveness, which can then be used to compare trade-offs between them.

For suppression efforts, several effectiveness measures can be created. During initial attack, there is a nominal payoff for building fireline, but a very large payoff for building the last few chains of fireline that classify the fire as "contained." Despite all the crews work, if those last few chains are not built then the fire could escape and their efforts were ineffective. So, an effectiveness measure would contain an element that captures the crew's ability to build the last few chains and contain the fire.

For readiness issues, a measure can be created that captures the number of particular types of forces which can be deployed to specific areas by a specific time. The measure in this case should not be how fast a tanker can fly or an engine crew can travel, because a tanker stationed two states away may not be as effective as an engine crew stationed in a neighboring region.

For the difficult task of protecting the wildland urban interface, a measure of effectiveness can be the status of the structures being protected. For example, and poorly designed measure could make the crews look good if 90% of the fire is contained, even though the last 10% destroyed the structures being protected. Therefore, the measure could contain the percent of targets protected.

These are just a few examples of effectiveness measures and their use in wildland fire that provide valuable insight to the performance of firefighting agencies. With properly designed performance measures, managers can assess how far they have come in attaining their goals, in this case, how far they have come to reduce the fire's ability to inflict damage on our natural resources and communities. The key is to recognize the structure of a good performance measure, a measurement that contains quality as well as quantity, and then begin gathering data that is both relevant and measurable.

SCALABIITY (Q1B, Q7, Q9B, Q10)

The issue of scalability of the CEA system needs careful consideration. CEA techniques can be applied at various scales, from the project level to strategic planning levels. Also aggregation of cost and effectiveness information from the planning unit to the national level is essential as is the ability to disaggregate. These issues would apply to any planning system or model employed by the agencies and has implications for budget formation, budget allocation as well as addressing issues of performance accountability at various levels of the agency.

Key economic considerations in scalability are economies of scale, jointness in production and cost. Many environmental problems exhibit important economies of scale. For example, the cost of treating many pollutants, such as arsenic in water, are known to be sensitive to scale. Similarly, research in fire has shown that fuels treatments and suppression costs are exponentially sensitive to scale. Also, as scale is expanded cost savings in the production of multiple measures of effectiveness are more likely to be encountered. This offers the possibility for “economizing” on the cost of effectiveness by taking advantage of “jointness” in cost. For example, it is well known that the treatment of hazard fuels can also promote beneficial ecosystem effects.

These considerations of scale and jointness are important considerations and often difficult to address. While many of the issues are technical, most would agree that consistent cost accounting standards and scale related issues should be applied to provide consistency in budgeting and in reporting of performance. No system will be perfect in this regard, but a system that is “good enough” should be sought.

ANSWERS TO QUESTIONS PROVIDED BY HOWARD ROOSE

Each of the original questions provided by Howard Roose (see Appendix A) are summarized and answered below with reference to the economics developed above. Questions often contained multiple parts. For example question “1” contains two questions. We summarized and labeled these as Q1A and Q1B for quick reference.

Q1A: What valuators should be used for selecting strategies?
Performance evaluators, or measures of effectiveness need to be very carefully considered, planned, monitored and implemented. The success of a CEA system largely depends upon the construction of appropriate performance measures. See the section above “Measuring Effectiveness” for information on constructing particular performance measures. Indexing is one tool that can be used to view and manage multiple measures. See the section above “Constructing and Effectiveness Index.” Broader or strategic measures, such as protection levels, are often more difficult to measure and proxy measures involving intermediate outcomes may be applied. For example, the level of protection in the WUI may not be possible to directly measure, but intermediate results such as quality acres treated in and adjacent to the WUI may provide an adequate proxy. Or the percentage of structures with appropriate defensible space could be used.

Q1B: What types of evaluators should be used for initial attack that could be expanded to address the full scope of fire management activities?
Key indicators of performance for initial attack have been the percentage of fires escaping initial attack and acres burned by contained fires. These can be reviewed and improved upon by introducing quality adjustors such as values at risk. Coordinating these with measures of treatments that involve ecosystem management poses one of the most difficult challenges of such a project. The geographic and temporal scales are likely to differ for effectiveness measures. For example, initial attack is often treated with annual resolution while investments in ecosystem function may pay-off over many years. This is a topic that will require additional research. Nevertheless there are key economic approaches and principles that can be applied. These include recognizing potential jointness between such objectives (see above sections CEA With Multiple Measure of Effectiveness and Scalability). Also, principles of investment management can be applied to compare current investments in effectiveness that may provide improvements over long periods of time.

As the initial attack model of the FPA is constructed, special care could be given to ensuring that ecosystem management and fuels management can be well integrated to provide an holistic approach. Such an approach would recognize potential cost savings. Here different measures of effectiveness will need to be managed.

Q2A: Would managers develop separate effectiveness analysis for each objective and could these be aggregated into an index?
Separate effectiveness measures can be defined for each objective. The extent that effectiveness measures differ typically has depended upon the scale of application. More specific measures at the project level may be used while broader measures at the policy or strategic level may be applied. Hence, the answer depends to some extent upon the scale of applications. Such measures can be combined into an index once shadow prices have been estimated. See the above section "Constructing an Effectiveness Index."

Q2B: How to develop shadow prices and compare disparate effectiveness measures.
Shadow prices can be developed along the discussions above entitled "Shadow Prices" and "Constructing and Effectiveness Index." In short, shadow prices can be approached using Ex Ante information on relative values or during the analysis by performing sensitivity analysis or programming to reveal prices implicit in the generated outcomes. A good system will clearly reveal the shadow prices so they can be checked for internal viability. Internal and externally generated information can both be used to provide consistency.

Failure to apply shadow prices in the analysis will only lead to implicit shadow prices. For example, different effectiveness measures involving scarce resources will necessarily have implicit shadow prices. We would encourage for explicit prices such that more informed and defensible decisions can be achieved. In short, it is not possible to avoid shadow prices.

Q3: How would managers know if alternatives are on the cost effective frontier? (See the section entitled "Single Measure of Effectiveness").
There are two ways to determine if solutions are on the frontier. First is by comparing different alternatives and by generating enough alternatives to identify the frontier. A second approach would be through optimization programming where alternatives are programmed or generated by programming to identify the optimal management strategy. The optimal strategy is defined by the point on the cost effectiveness frontier that intersects the budget line. This would correspond with point A in the first figure in Panel A on page 5. Assume the horizontal line is a budget level.

Q4: How many alternatives should be tested?
Enough alternatives need to be tested to reveal the frontier. Typically, most alternatives represent interior solutions. Managers can learn from interior solutions so as to better enable them to produce alternatives closer or on the frontier. Programming can also be used to more efficiently identify the frontier.

Q5: What principles should managers use to identify the point of diminishing returns on the CEA frontier and should points laying beyond this point not be justified?

(See above section "Single Measure of Effectiveness and CEA with Multiple Measures of Effectiveness).

Diminishing returns occurs wherever the slope of the frontier increases (second derivative is positive). The point to be obtained would be consistent with the budget level and/or consistent with the shadow prices. This is developed at some length in the sections above on single and multiple measures of effectiveness.

There can be value in identifying points beyond those consistent with the budget or shadow price as they may provide additional information on the planning system and on planning alternatives. This may enable managers to better construct viable alternatives and enable them to better respond to budget increases or decreases or to changes in shadow prices.

Q6: What would be the basis for allocating less than the preferred budget?

The economic theory and principles for responding to alternative budget levels in the context of tradeoffs in the effectiveness measures is well developed under the above heading **"Changing the Budget Level."** The reader is referred to that section.

Q7: For a given set of performance target levels with alternative organizations to satisfy them, is the solution to price them out and select the least cost organization?

Assuming fixed performance targets assumes much of the CEA process away and turns the process into one of cost accounting. See discussion under "Single Measure of Effectiveness" regarding a fixed target. Much strength and richness is added to the analysis by treating effectiveness as variable. To the extent that there are alternative objectives (effectiveness measures) with different costs, they would all be "priced out," compared and viewed in terms of the budget and relevant shadow prices. Various objectives may share in the resource base, thus reducing the overall cost of a strategy. Advantages to scale and jointness in cost can be addressed to arrive at more cost effective solutions. See the above discussion entitled "Scalability."

Q8A: Should initial attack success be evaluated in terms of "threshold damage limits" and how would ecosystem benefits from wildland fire use be factored into the system?

The answer to this depends upon what is meant by "threshold damage limits" and the upon the context. It is possible that thresholds of damage or ecosystem effects could make the CEA frontier either lumpy or discontinuous. Such considerations imply additional care in the formulation and operation of any planning system. In a CEA system, effectiveness could be measured as providing distance between say the number of quality acres burned and the estimated threshold. Also, damage would not be directly measured because this would require estimating NVC. An effectiveness proxy for physical damage impact would presumably be used instead.

Q8B: How would ecosystem benefits be factored into this evaluator?
The incorporation of beneficial effects to damaging fires applies to the functioning of any fire management planning system. If the point of the threshold is to avoid some critical level of damage, then this depends upon the extent that benefits would affect the location of the threshold. It would seem unlikely that beneficial effects would affect the location of most thresholds. But this all depends upon what is intended by the question. If threshold means a "target" level with no consideration of progress toward the target, then the CEA framework is assumed away, the problem is one of cost accounting of alternatives. This issue is addressed in several sections above.

Q8C: How can the bureaus prevent land managers from compromising the integrity of FPA by adopting unrealistic initial attack objectives in LMPs, such as very low threshold damage limits, or an objective that no fire shall get larger than 1 acre in size?
Unrealistically aggressive objectives would imply exceptionally high cost levels in a CEA framework and would be revealed as such. Therefore, properly applying using CEA framework would associate "very low threshold damage limits" as being either not cost effective or as being too costly. The CEA framework is intended to address this kind of issue. The question again implies the use of fixed quantities of objectives which can severely limit the usefulness of the model.

In short, the question reveals three issues that can addressed by development of the understanding of the CEA theory:

1. estimation of damages as opposed to effectiveness,
2. the use of "targets" or fixed quantities of outcome,
3. the inclusion of cost in a CEA model.

Q8D: Or conversely they could adopt very nebulous objectives such as "restore ecosystem health" without quantifying indicators and measures of this that would be needed to drive a cost-effectiveness analysis. Such unrealistic or nebulous objectives could generate massive initial attack organizations…"

The question correctly implies that if CEA is improperly performed that the results may be undesirable. Key features of CEA are that measures of effectiveness must be carefully constructed and measurable (see the section entitled Measuring Effectiveness above). Some strategic level goals may be vague and require that intermediate products be measured as a proxy for attaining progress toward the goal. A great example was provided by another author. Measurement of effectiveness depends critically upon the planning level. At the strategic level, goals may be somewhat nebulous and difficult to measure. At the intermediate or tactical level, empirical indicators of progress toward the strategic goal can be measured. Proxy measures related to treatments and ecosystem condition can be established and used to measure progress toward attaining the strategic goal. This process of applying measures of intermediate products toward final goals is applied through out management and science. For example, in science broad conditions, often stated as laws that provide broad direction to guide thought and knowledge. However, the empirical testing of progress and applicability is carried out through the formulation and administration of hypotheses.

The nebulous goal of combating heart disease is often addressed by administering, cholesterol reducing drugs. Typically, effectiveness is measured through the intermediate product of reducing cholesterol levels which are easily measured. This is then used as one proxy for progress in the nebulous fight against heart disease. There are many more examples from education, medicine, national defense and even fire.

Q9A: Could each planning unit determine a preferred strategy that would be most cost effective in accomplishing all goals and objectives by using shadow pricing or placing weighting values on goals?

The CEA framework and theory can be used to estimate a preferred strategy. The use of multiple goals, shadow pricing and weights were addressed at length in the above sections entitled "CEA With Multiple Measures of Effectiveness," and "Shadow Prices."

Q9B: Could the cost of preferred strategies from various planning units be aggregated by state, region or nationally to establish the preferred budget for the fire program?

Aggregation to the national program level is a requirement to successfully address national issues of budget, accountability and appropriation. Hence, aggregation and desegregation should be a clear requirement of such a system. This will likely require establishment of clear standards for cost accounting and aggregation as well as standards for addressing the accumulation of effectiveness measures. Key standards defining which measures of effectiveness to aggregate or to keep separate would also need to be established. See the section above entitled "Scalability." This is a key issue that will need substantially more work and development.

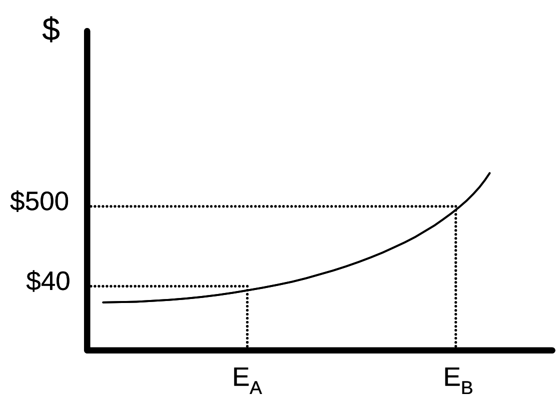
Q9C: What would be the basis for allocation less than the preferred budget?

See the above section entitled "Changing the Budget Level." (p.8).

Q9D: Without consistent rules for establishing goals and objectives (and shadow prices?) what is to stop a unit from ratcheting down the objectives to show that the best organization for their unit will cost only $40 million in order to gain an advantage over another unit that justifies a $500 million request?

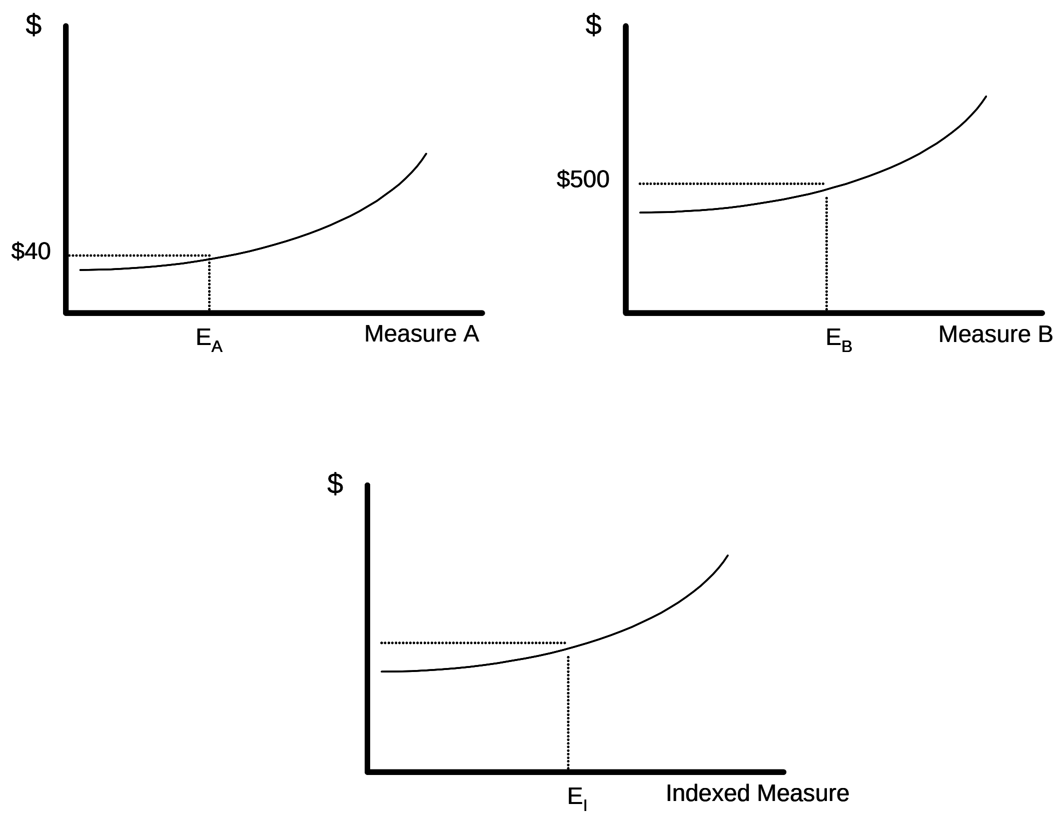
The answer to the question depends upon what is meant by the definitions of goals or objectives and by the best organization. We provide three answers based upon three plausible interpretations to the question.

1. Assume two planning units, A and B, using the same effectiveness measure, but unit A intends to produce less than unit B. Both units are efficient in that they both operate on the frontier.

   Under these conditions, the funding choice is involves purchasing different amounts of effectiveness at different costs. Unit A costs less, but provides less effectiveness while Unit B costs more but provides more effectiveness.

2. Assume the two planning units are producing different effectiveness outputs but they are both efficient such that they are each operating on the effectiveness frontier. Comparison will require implicit or explicit indexing. By using shadow pricing (see above sections on multiple goals and shadow pricing) an index can be created to provide an overall measure of effectiveness that corresponds with a total cost that would typically be $540 or less. Presuming that the planning units each provide their cost effectiveness information, a selection along the indexed effectiveness measure can then be made and disaggregated back to the two planning units. This is illustrated in the figure below.



Q10: How will FPA evaluate the cost effectiveness of regional and national resources?

We assume that this question refers to strategic resources such as strategically located air support (tankers, smoke jumper base etc.) that are not allocated to a specific planning unit. The cost of such resources would be included at a level commensurate with the scale of benefit that they provide. Such resources would be included at the regional or national level of aggregation or analysis. The procedures for inclusion (or keeping them separate) would depend upon the nature and scope of the FPA and its related architecture. Inclusion should address strategic cost advantages and increased effectiveness applied to the overall system. Regional and national effectiveness analysis needs to be aware of issues of scalability including cost savings related to jointness in cost and economies of scale. These were addressed above in the section entitled "Scalability."

Q11A: Should we set an interagency national performance target for large fires that does not directly consider the cost of suppression and damages from these fires but is expressed in terms of the number of and acres burned by large fires?

No. The alternatives suggested in the question should be rejected. Incorporating effectiveness measures such as quality acres treated or protected does not imply that costs or damage is ignored. Costs should be carefully considered as well as relevant resource impacts so the most advantageous program can be analyzed and constructed.

Q11B: Since large fires have much greater impact on ecosystem health than small ones that are caught with initial attack, should they (the targets for large fires) be factored in somehow to local unit goals and objectives? If so how?

Using CEA does not imply that targets cannot be incorporated into the analysis. CEA will enrich the context in which targets are used in the analysis. For example, a target could be used to define the end of the effectiveness axis and effectiveness measured as progress toward the "target." Much care should be exercised when working with "national targets." National targets that are applied to local units can have adverse economic implications when economies of scale and differences in local conditions are not considered. For example, differences in ecosystems might imply that different levels of effectiveness or targets should be considered. For some ecosystems suppression success can be obtained at little cost whereas in other ecosystems suppression can be costly. Also, economies of scale are important considerations.

APPENDIX A: Questions Provided by Howard Roose

Steve Bott/Stewart Lundgren
7/15/2002i

Questions Relating to the Economic Theory Guiding Fire Program Analysis System

1. Fire Program Analysis (FPA) System proposes to simulate the outcomes of various fire management strategies (i.e. alternatives that combine fire suppression, fire use, prevention, hazard fuels reduction, prescribed fire for ecosystem health, and post-fire rehabilitation) in a geo-spatial environment, both spatially and temporally. Managers must have some basis for evaluating the cost effectiveness of one alternative over another in achieving land management objectives. A chief criticism of NFMAS relates to the C+NVC curve and the prices used in the analysis process. If we are to design a program needs analysis based on land management objectives as a replacement for a single composite economic indicator such as C+NVC (priced-based measures), what evaluators would managers use as the basis for choosing one strategy over another? What types of evaluators could be developed for the effectiveness of initial attack organizations and preparedness in general that later could be expanded to cover the entire scope of fire management activities listed above?

2 (a). Would managers develop a separate cost effectiveness analysis for each effectiveness measure (objective)? If developed, could these be aggregate into a composite CEA index reflecting tradeoffs between all objectives?

(b). How would a planning unit develop consistent shadow prices to compare effectiveness for different types of objectives? E.g. how would managers quantify consistent decision rules for comparing the effectiveness of a given strategy both in restoring ecosystem health and in protecting structures in the wildland urban interface? What if these were evaluated separately?

3. If managers simulated several alternative programs each costing about the same, they should be able to determine which are cost effective. (by measuring the incremental effectiveness of each scenario). They also should be able to identify how an increase or decrease in the budget level would affect the level of effectiveness. How would they know if any of the alternatives were on the cost effectiveness frontier (i.e. an alternative that would be more effective but cost the same would not exist)?

4. Likewise, how many different wildland fire management alternative programs should be tested in order to determine the shape of the cost effectiveness frontier (i.e. could cost effective alternatives exist that cost more or less than the alternatives already tested)?

5. According to the classic cost effectiveness diagram, the slope of the cost effectiveness frontier increases from left to right. This results in an additional increment of cost yielding an ever diminishing increment of effectiveness. What principles should managers use to identify a point of diminishing returns on the cost effectiveness frontier ? Would alternative

programs lying beyond this point of diminishing returns not be economically justified and should they not be used as the basis for budget formulation?

6. Each planning unit could determine a preferred cost effective strategy for accomplishing all goals and objectives (by using shadow pricing or placing weighting values on goals). And the cost of preferred strategies from various planning units could be aggregated by state, region or nationally to establish the preferred budget for the wildland fire program. But what would be the basis for allocating less than the preferred budget to field units. E.g. if the appropriation was only 80 percent of the total preferred budget (CEL), how would managers evaluate tradeoffs between the goals of different planning units?

7. For the FPA Phase I preparedness model, we could adopt a criterion of success such as "98% of all fires will be kept to less than 300 acres in size". This would equate to one of the performance measures being developed for the 10-year strategy. We could meet that objective with any number of alternative initial attack organizations (helicopter based versus engine based versus hand crew based). Each of these organizations would have a different cost. But Phase I may also want to evaluate other preparedness and suppression objectives, such as specific protection goals for the WUI, a reduction of large suppression actions to some target level, or factor in wildland fire use to restore ecosystems as part of a comprehensive "suppression" alternative. Is the solution to find an array of organizations that can meet these objectives, price them out, and then select the cheapest? If so, how would the FPA display tradeoffs between such objectives?

8. Should initial attack success be evaluated in terms of "threshold damage limits by land allocation" as has been attempted in the Forest Service? If so, how would ecosystem benefits from wildland fire use fires be factored into this evaluator? How can the bureaus prevent land managers from compromising the integrity of the FPA by adopting unrealistic initial attack objectives in LMPs, such as very low threshold damage limits, or an objective that no fire shall get larger than 1 acre in size? Or conversely, they could adopt very nebulous objectives such as "restore ecosystem health" without quantifying indicators and measures of this that would be needed to drive a cost-effectiveness analysis. Such unrealistic or nebulous objectives could generate massive initial attack organizations that cannot be supported by allocated budgets, and would exacerbate the problem of allocating between units described in "9". below. Or they could prevent FPA from identifying the cost-effectiveness of alternatives due to the lack of specific measures of effectiveness (this question may relate more to how fire managers can influence the land management planning process than to the economic basis of FPA, however it may be worth some thought from the economists since the economic theory will have to work in the real world)

9. Could each planning unit determine a preferred strategy that would be most cost effective in accomplishing all goals and objectives by using shadow pricing or placing weighting values on goals? Could the cost of preferred strategies from various planning units could be aggregated by state, region or nationally to establish the preferred budget for the wildland fire program? Assuming this could be done, what would be the basis for allocating less than the preferred budget to field units. E.g. if the appropriation was only 80 percent of the total preferred budget (CEL), how would managers evaluate tradeoffs between the goals of

different planning units? Without consistent rules for establishing goals and objectives (and shadow prices?) what is to stop a unit from ratcheting down the objectives to show that the best organization for their unit will cost only $40 million in order to gain an advantage over another unit that justifies a $500 million request?

10. How will FPA evaluate the cost effectiveness of regional and national resources? Should the cost of these resources be factored into FPA through a national cost effectiveness analysis for the entire program that includes the preferred scenarios from the local planning units plus regional and national program management and resources? How do we measure the effectiveness of regional and national program management?

11. Should we set an interagency national performance target (program outcome) for large fires that does not directly consider the cost of suppression and damages from these fires but is expressed in terms of the number of and acres burned by large fires? Since these fires have much greater impact on ecosystem health than small ones that are caught with initial attack, should they be factored in somehow to local unit goals and objectives? If so, how?

APPENDIX B: EXCEPRT FROM RIDEOUT AND HESSELN 2001

Principles of Forest and Environmental Economics (Second Edition). 2001.

COST EFFECTIVENESS ANALYSIS

Many projects are intended to produce benefits that may not be feasibly measured. Difficulty in measuring and monetizing benefits occurs for several reasons. For example the benefits may be defined in a vague way, or they may be well defined, but too costly to measure. A classic example is valuing human life—the value is both difficult to define and costly to measure. There are many similar examples in forestry and natural resources. Another situation that gives rise to measurement difficulties is when projects produce public goods. Measurement is difficult partly because of the intangible nature of the benefits, and partly because of the non-exclusive nature of benefits. For these reasons, CEA is often used to analyze problems of national defense, public health and disaster prevention. In CEA, defining the measure of effectiveness is often crucial to success (Gold et al. 1996).

Consider Sequoia-Kings Canyon National Park, home of the President's Grove of Giant Sequoias. Such a national treasure invokes a full range of values (see Chapter 8)—from use values, including market and non-market, to intrinsic values. Attempts to monetize the full range of value for this resource are likely to be costly and met with skepticism regarding the validity of the estimate.

Cost effectiveness analysis (CEA) is a subset of benefit cost analysis that does not include or incorporate measures of value or price. CEA comes in two equivalent forms as can be seen in the definition.

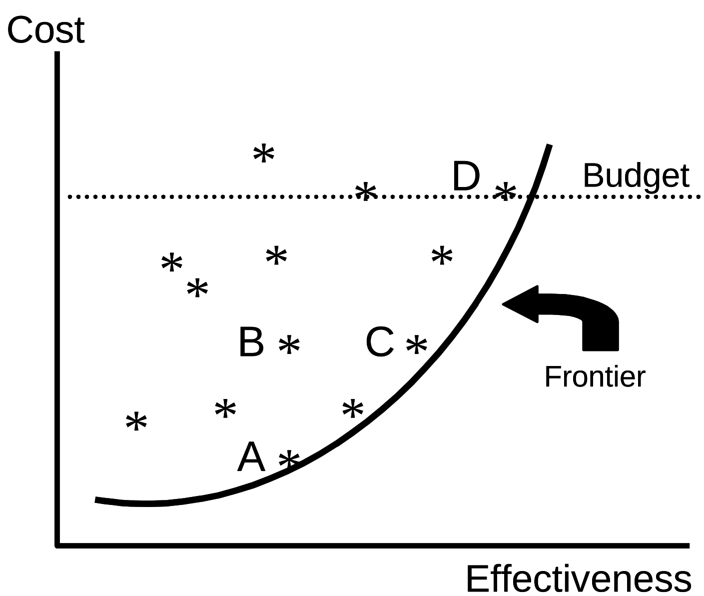
> ***Cost effectiveness analysis (CEA)*** *seeks to maximize the attainment of a particular goal for a given budget, or to minimize the cost of attaining a specified goal.*

The second part of the definition, minimizing the cost of attaining a goal, suggests that the goal has been specified and will likely be within budget. We are to seek only the least cost means of attaining the goal.

BASIC CEA

The CEA process can be quite useful in sorting out inefficient projects to better define problems. Suppose, for example, that several projects are evaluated, but that benefits are currently unknown and no attempt is to be made to estimate them. We can often define and record a physical measure of effectiveness for a goal, that each of our projects would produce, and we could also record the cost of implementing each project. With the cost and effectiveness of each project recorded, we can then chart the various projects as in the illustration below. Each project is denoted by an asterisk in cost-effectiveness space. We are now in a position to perform elementary CEA on our set of projects. Projects that lie on the lower right form the CEA frontier—denoted by the upward sloping curve. Projects on the frontier would be considered to be technically efficient alternatives. For example, consider project B relative to project C. Project C is superior because it produces more effectiveness at the same cost. Project B is also inferior to project A because it costs more to produce the same level of effectiveness.

The power of CEA is that with a well-defined, physical measure of effectiveness, an analyst can quickly narrow down the scope of projects to be considered –often to just a handful because only projects on or near the frontier should be considered. Project B is inferior and can now be removed from consideration. Projects remaining on or near the CEA frontier are technically efficient and analysts should now focus on these. Unfortunately, there is no way left to choose between projects A and C which fall on the CEA frontier. This is often left as a policy or budget consideration.



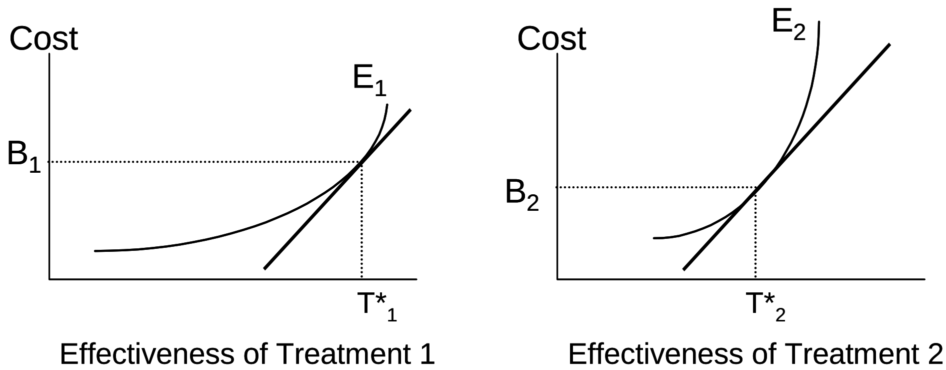
Cost effectiveness analysis.

This section showed the basic structure of CEA and its strength enabling-managers to quickly eliminate inferior projects and to focus on those that are technically efficient. It also exposed a key weakness in that CEA cannot provide guidance between similarly, technically efficient projects.

CEA WITH A BUDGET CONSTRAINT

In many instances CEA is performed within the context of a budget constraint. If the objective is to attain the most effectiveness for a particular budget level, then project D would be selected. Project D is technically efficient, it is on the CEA frontier, and it matches the budget. Project D would be chosen if the projects in the analysis are mutually exclusive. Alternatively, if the projects are not mutually exclusive, then the group of projects collectively maximizing effectiveness would be chosen (not illustrated).

An interesting application occurs where various treatments are being evaluated in a CEA framework. Suppose that we are considering two treatment types T_1 and $T_{2,}$ producing a common measure of effectiveness and are both funded from a common budget. It can be shown (see mathematical appendix) that once the effectiveness frontiers are formed that the optimal use of the budgets is to fund each project until the *ratio* of marginal effectiveness (slope of the effectiveness curves) is equal to the ratio of the unit cost of each treatment. If the unit costs of treatment are the same, then each treatment would be funded until the slopes of along the two effectiveness frontiers would be equal, as in the figure below.



CEA with two treatments and budget constraint.

In the figure, treatment one (T_1) is funded to B_1 and treatment two (T_2) is funded to B_2 producing a total budget of $B = B_1 + B_2$.

While CEA has important limitations, it also has useful strengths. Without knowing the benefits, we can often sort through the array of potential projects to further focus on those which are cost effective. In the face of a budget constraint, funding a project or projects that provide the maximum effectiveness for a budget can be useful. Where alternative treatment types are under consideration with a budget constraint, CEA provides clear guidance for expending the budget between the two treatments. At some point in the analysis, the issue of the benefits of the treatment will arise and while CEA cannot directly address this issue it can position the analyst to communicate how alternative benefit estimates would affect the results. A further implication of the benefit valuation and the budget constraint is developed in the mathematical appendix to this chapter.

MATHEMATICAL APPENDIX to CEA

This appendix expands the CEA developed in the chapter to derive the principle that when two treatments are used to produce one measure of effectiveness under a budget constraint, that the ratio of the rates of effectiveness should equal the ratio of the unit treatment costs. The analysis also reveals the ironic result that the value of effectiveness is potentially inferred by the shadow price on the budget constraint. Consider the following maximization assertion:

$$\text{Max (TE)} = E(T_1) + E(T_2) - \lambda[w_1T_1 + w_2T_2 - B]$$

Where: TE denotes total effectiveness.

E denotes effectiveness from treatments T_1 and T_2.

λ denotes the Lagrangian multiplier

w_1 and w_2 denote the unit costs of treatments T_1 and T_2 respectively

B denotes the total budget expended on treatments.

The first order conditions are stated as:

$$\frac{\partial(CE)}{\partial T_1} = \frac{\partial E}{T_1} - \lambda w_1 = 0$$

$$\frac{\partial(CE)}{\partial T_2} = \frac{\partial E}{T_2} - \lambda w_2 = 0$$

and

$$\frac{\partial CE}{\partial \lambda} = B - (w_1 T_1 + w_2 T_2) = 0$$

Assuming the second-order conditions hold, interpretations of these first-order conditions are of some interest.

The first two partial derivatives are best interpreted as a ratio. Dividing the first two yields the ratio:

$$\frac{\frac{\partial E}{\partial T_1}}{\frac{\partial E}{\partial T_2}} = \frac{w_1}{w_2}$$

stating that the ratio of marginal effectiveness (slopes of effectiveness frontiers) must equal the ratio of the unit costs of treatments as illustrated in the text. The last partial derivative ensures that the budget is exactly spent.

Perhaps more interesting is the interpretation of the Lagrangian multiplier λ (Lambda). Lambda is the shadow price on the fixed budget (B) or $\frac{\partial TE}{\partial B} = \lambda$. That is, λ denotes the marginal contribution of budget to the promotion of effectiveness. To the extent that the budget is a measure of willingness to pay for effectiveness (E), λ is the implied price (marginal value) of effectiveness. The irony is that the reason to perform CEA is often that benefit information is lacking, too expensive to gather, or unreliable. Note that this development requires that E is identically defined for each treatment.